SKELETAL MUSCLES STRENGTH RESPONSE TO FUNCTIONAL LOW FREQUENCY ELECTRICALSTIMULATION IN CHRONICHEART FAILURE

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Abstract

Purpose: The aim of this study was to evaluate the effect of functional low frequency electrical stimulation of quadriceps and calf muscles on muscles strength and in patients with chronic heart failure (CHF).

Methods: Fifty patients with chronic heart failure (CHF) were randomly selected from Cairo university hospital, their ages ranged from 40 to 60 years. They were divided into two groups, thirty patients for study group, and twenty patients for control group. Each patient in the study group received functional low frequency electrical stimulation with frequency 5 sessions per week for three successive weeks, in addition to medical treatment. Each patient of the control group received the same medical treatment, Pre and post study muscles strength assessment was done for each patient of both groups

Results: The result of this study revealed statistically significant difference in muscles strength that showed a statistically significant improvement in patients for the study group in comparison to control group.

Conclusion: Functional low frequency electrical stimulation of quadriceps and calf muscles improved muscles strength in patients with chronic heart failure, and offered an alternative training mode. Thus we recommended using functional low frequency electrical stimulation of quadriceps and calf muscles in order to improve muscles strength, reduce pain and swelling in patients with chronic heart failure.

Key words: Functional electrical stimulation, skeletal muscles, chronic heart failure.

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Introduction:-

Heart failure (HF) is defined as a complex clinical syndrome that can result from any structural or functional cardiac disorder that impairs the ability of the ventricle to fill with or eject blood. The major causes of HF are coronary artery disease, hypertension, cardiomyopathy, and valvular heart disease [26].

Congestive heart failure (CHF) is a condition in which the heart is unable to pump the necessary amount of blood throughout the body. This causes blood to back up in the veins. Fluid pools in the liver and lungs. Swelling occurs first in the feet, ankles, and legs, and then throughout the body as the kidneys begins to retain fluid [12].

The main symptom of HF is the progressive decrease in functional capacity associated with dyspnea with prognostic implications independent of LVEF. The pathophysiological process of HF will eventually lead to skeletal muscle weakness and atrophy, and when the symptoms will affect daily activities, to a sedentary lifestyle and social isolation with an impact on the prognosis of the patient. CHF-related skeletal muscle dysfunction is the result of an ongoing imbalance in the activation of anabolic and catabolic pathways and has been shown to have significant prognostic importance [20].

Congestive heart failure is a clinical syndrome with a complex pathophysiology initiated by left ventricular dysfunction leading to systemic and pulmonary congestion and elevated peripheral vascular resistance. Fluid retention along with peripheral vasoconstriction and reduced skeletal muscle perfusion provides the pathophysiological basis for the symptoms. Coupled with inactivity the stage is set for deconditioning. Skeletal muscle atrophy, changes of fiber-composition (i.e. an increase of type II fibers which are mostly anaerobic, at the expense of aerobic type I fibers), reduced capillary density and reduced cytochrome oxidase activity characterize the condition [1].

The syndrome of chronic heart failure (CHF) is typically characterized by decreased exercise capacity with reduced peak oxygen consumption. The exercise abnormalities are closely related to impaired skeletal muscle behavior. The skeletal muscle oxidative metabolism is depressed, intracellular PH level decrease, phosphocreatine depletion during exercise and phosphocreatine resynthesis decreases the increased sympathetic tone, stimulation of the rennin-angiotensin-aldosterone system influences the redistribution of regional blood flow and creates endothelial dysfunction of all vessels. This leads to an impaired peripheral vascular dilatation in response to vasodilator stimuli reduction of blood flow and O_2 supply in skeletal muscles [19].

Chronic heart failure is often accompanied by complete hypoperfusion, which affects a great part of the skeletal muscle mass. The intensity of catabolism increases, the reactive oxygen species and a large amount of circulating cytokines stimulate the development of apoptosis (apoptosis which is an energy dependent programmed cell death for removal of unwanted individual cells). Chronic hypoxia strongly damages the structural and metabolic integrity of muscle fibers. The resulting general atrophy decreases the power and fatigue resistance of muscles. Sometimes, this situation progresses to cardiac cachexia [14].

Patients with chronic heart failure develop significant skeletal muscle atrophy and abnormalities in skeletal muscle metabolic function. These skeletal muscle alterations may contribute to exertional fatigue which is a major limiting symptom in patients with CHF. The cause of the

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atrophy is related to disuse, repetitive ischemia linked to reduced blood flow on exercise [27].

The beneficial influence of exercise on the aero-metabolic capacity and fatigue tolerance in patients with chronic heart failure has been repeatedly reported. The commonly used methods of training, however, are based on systemic exercise and are not always tolerated by all CHF patients, especially by those with severe heart failure or with life-threatening arrhythmia. Anew approach to cardiac rehabilitation is represented by the method of low-frequency electrical stimulation (LFES) of skeletal muscles. In vitro conditions, a LFES of 10 Hz changes the phenotype of stimulated mammalian skeletal muscle fibers. LFES transforms the myosin chains of ”fast” type to ”slow” type ones, which is characterized by a higher resistance to fatigue LFES and also increases capillary density and enhances perfusion in strength muscles. The most important is the fact that all these experimental results are also applicable to human condition [13].

The leg musculature seems to be affected the most, also displaying a higher percentage of type II fibers, lower activities of mitochondrial enzymes, and a decreased capillary density. Isometric strength of the knee extensor muscles in patients with CHF is markedly lower due to a smaller muscle cross -sectional area: neuromuscular electrical stimulation (NMES) is in widespread use to delay atrophy of skeletal muscles associated with disuse in both disused and healthy muscles with the same efficacy as voluntary contraction. NMES allows training of skeletal muscles without active exertion. Thus patients with CHF using NMES could achieve positive training effects without facing the fear of over exertion or dyspnea probably appearing in voluntary exercise [27].

Many patients with severe CHF are unable to undertake more intensive physical activity. Peripheral muscles are weaker with a decreased mass, reduced aerobic capacity and increased susceptibility to fatigue. Low frequency electrical stimulation, such as used in our study, has previously been shown to produce an increase in oxidative capacity and improve muscle strength, without volume over load cardiopulmonary system [28].

Neuromuscular electrical stimulation (NMES) applied to leg muscles offers an alternative training mode and represents an attractive option for CHF patients who are unable, non-adherent or unwilling to exercise. NMES consists of repeated, rhythmic stimulation of skeletal muscles in a static state, using skin electrodes positioned on the thighs and calf muscles, at an intensity that will lead to visible muscle contractions. The stimulator delivers a biphasic current of low frequency (10–25Hz), with gradually increasing stimulation amplitude of 40–80 mA maximized to the pain threshold of the subject. NMES has been consistently shown to elicit positive effects on functional capacity and skeletal muscle adaptations in patients with HF and unable to participate in traditional aerobic and/or resistance training programs at an appropriate stimulus [10].

In addition, there is a difference between conventional training and LFES training. In conventional exercise, more muscle groups are utilized and there are significant changes in central homodynamic variables. Electrical stimulation affects only a low number of muscle groups and makes the training safe even in patients with severe forms of CHF ; LFES can be considered a safe and well tolerated method that has no life-threatening side effects [11].

Purpose of the study:

Low frequency electrical stimulation (LFES) of the lower limbs may improve the skeletal muscle structural and functional patterns in chronic heart failure, including muscle strength.

Subjects, Material and Methods

A group of 50 patients (30males and 20females) diagnosed with CHF, classified as New York Heart Association (NYHA) classes' III to IV, were included in the study. They were selected from Kaser El Aini hospital.

Their age was ranged 40-60 years. The mean age of the study group was (47.4 + 5.6 years) and control was (47.5 + 5.7years).

Their mean ejection fraction (EF) was less than 30 %. $E_f = \frac{SV}{EDV} = \frac{EDV - ESV}{EDV}$

All patients were on optimal pharmacological treatment (angiotensin converting enzyme inhibitor (ACEI,) beta blockers diuretics). They were divided into two groups; study group 30 patients and control group 20 patients.

Evaluation equipment

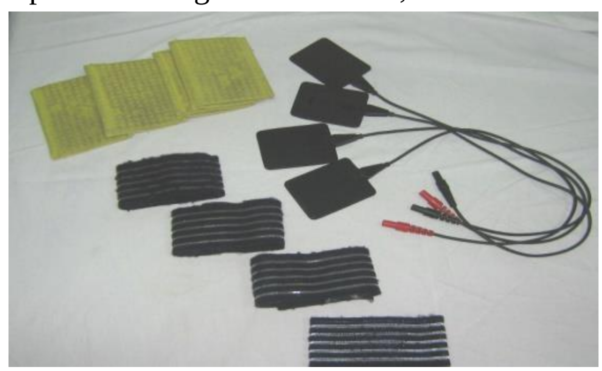
Muscle strength measurement to determine the maximal muscle strength the Lafayette muscle test system (USER MANUAL) (MMT) Model 01163, White Plains, New York (10602) of quadriceps and calf muscles were performed .

Fig (1)
Lafayette Muscle Test System (Mmt)

Fig (2) Therapeutic equipment

Low frequency electrical stimulation

An Elpha 2000 dual-channel stimulator (Diameter, Odense, Denmark) was used. The stimulated muscles included quadriceps and calf muscles on both lower extremities. Special rectangular electrodes, 80 × 100mm



(St.Cloud International , Chantonnay , France), were used. (Jancik et al ,2003).

Fig (3) Electrodes and pads of electrical stimulation

Procedure of evaluation of muscle strength:

Manual Muscle Test System (MMT) of the quadriceps and calf muscles was performed before and after the end of the three weeks period of electrical stimulation.

All measurements were performed while the subject sitting ؛ the back well supported, the pelvis and knees flexed at an angle of 90 degrees. The patients then were carried

Out 3 consecutive maximal voluntary extensions (contraction time 3sec-resting

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time 7sec) the highest value was considered as the maximal strength

Fig (4) Muscle test (quadriceps)

Fig (5) Muscle test (Calf)

Fig (5) Muscle test (Calf)

Procedure of the study:

Preparation of the patient:

- Explain the procedure to the patient and the purpose of the study .
- Assessment of muscle strength (for quadriceps and calf muscle) and blood flow (by Doppler Ultrasound) were taken before starting the procedure .
- Attach the electrodes to the site of treatment (quadriceps or calf muscle).

Low frequency electrical stimulation:

Electrical stimulation was performed for one hour/day for five days a week for three consecutive weeks.

- The stimulator delivers a biphasic current of 10 Hz frequency.
- The pulse duration was 200 msec with an (on-off).
- Stimulus mode (20sec stimulation, 20 sec pause).
- The maximal stimulation amplitude was 60 mA.

The muscles to be stimulated were the quadriceps and calf muscles of both legs.

- ❖ For the quadriceps muscles surface electrodes 80×100 mm were positioned on the thighs approximately 5cm below the inguinal fold and 3 cm above the upper patella border.
- ❖ For the calf muscles the electrodes were positioned approximately 2cm under the knee joint and just over the proximal end of the Achilles tendon.

Fig (7) Electrical stimulation(quadriceps)

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Fig (8) Electric stimulation (calf)

Data analysis

The mean, standard deviation and the range will be calculated for all subjects. Paired "T" test will be used to determine the mean value of blood flow velocity and muscles strength for each subject before and after treatment program and to compare the changes with each group.

Results:-

Table (1) and fig (9) show the mean, standard deviation, maximum minimum of age, weight, height and BMI of the two different groups. These data include.

Group		Age (yr.)	Weight (Kg)	Height (cm)	BMI (Kg/m ^{2})
Treatment Group	Mean	47.4	75.1	158.5	29.9
	S.D.	5.6	6.09	5.7	1.9
	Max.	55	85	170	34.2
	Min.	36	60	150	26.6
Control Group	Mean	47.5	75	160.2	29.3
	S.D.	5.7	6.6	5.9	1.6
	Max.	55	85	150	33.7
	Min.	36	60	172	26.7
Significance		P>0.05**	P>0.05**	P>0.05**	P>0.05**

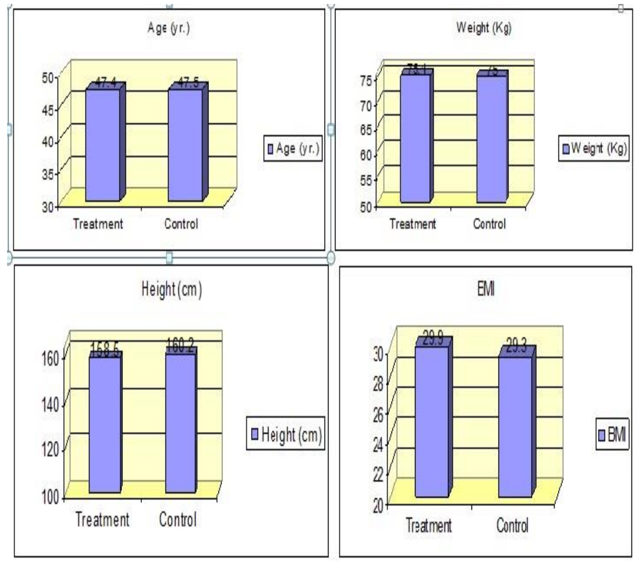

Table (2): Statistical analysis for muscle strength of the right quadriceps before and after the treatment program

Group / Parameter	Treatment Group	Control Group	t-value	P-value
Before program	9.7±2.9	10.2 ± 2.4	-0.63	P>0.05**
After program	16.2 ± 3.9	10.1± 2.51	6.75	P<0.05*
t-value	-16.1	0.37		
% of changes	% 67.29	% 0.98		
P-value	P<0.05 *	P>0.05**		

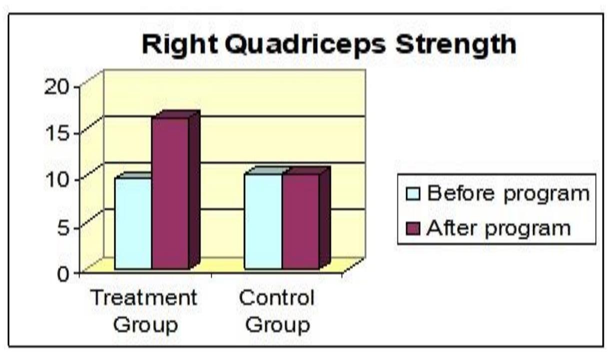

Fig (10): Statistical analysis for muscle strength of the right quadriceps before and after the treatment program.

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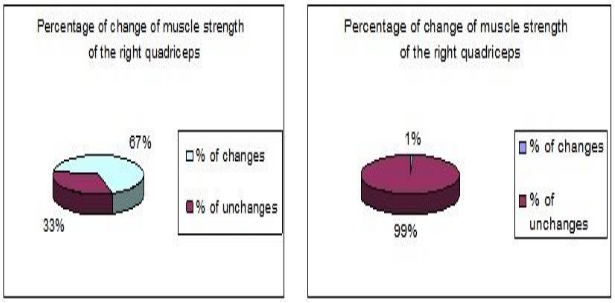


Fig (11): Percentage of change of muscle strength of the right quadriceps before and after treatment for study and control group

Table (3): Statistical analysis for muscle strength of the Left quadriceps before and after the treatment program

Group / Parameter	Treatment Group	Control Group	t-value	P-value
Before program	9.6±3.01	10.01 ± 2.56	-0.58	P>0.05**
After program	16.28 ± 3.89	10.2± 2.45	6.83	P<0.05*
t-value	-17.1	-0.49		
% of changes	%69.58	% -1.89		
P-value	P<0.05 *	P>0.05**		

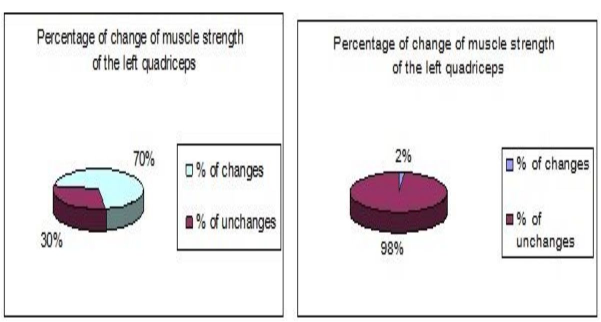


Fig (12): Statistical analysis for muscle strength of the Left quadriceps before and after the treatment program.

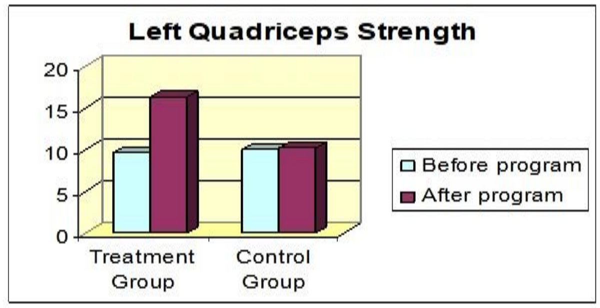


Fig (13): Percentage of change of muscle strength of the left quadriceps before and after treatment for study and control group.

Table (4): Statistical analysis for muscle strength of the right Calf muscle before and after the treatment program

Group / Parameter	Treatment Group	Control Group	t-value	P-value
Before program	5.56±1.49	5.37 ± 0.9	0.51	P>0.05**
After program	10.36± 2.5	5.37± 1.29	9.3	P<0.05*
t-value	-20.8	0.00		
% of changes	%86.33	%0.00		
P-value	P<0.05 *	P>0.05**		

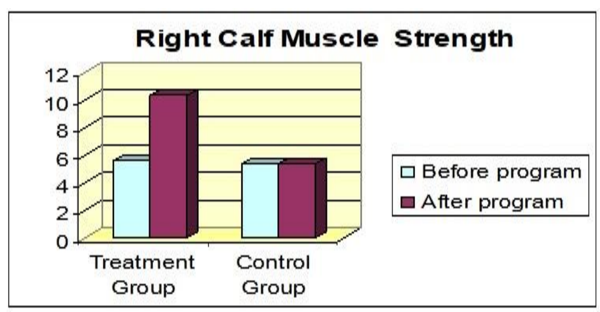
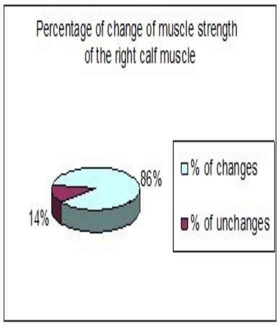


Fig (14): Statistical analysis for muscle strength of the right Calf muscle before and after the treatment program



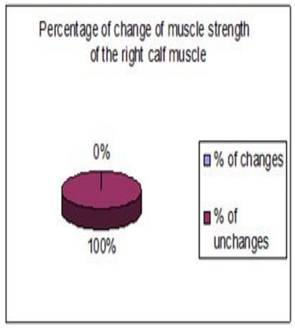


Fig (15): Percentage of change of muscle strength of the right calf muscle before and after treatment for study and control group

Table (5): Statistical analysis for muscle strength of the Left Calf muscle before and after the treatment program

Group / Parameter	Treatment Group	Control Group	t-value	P-value
Before program	5.56±1.53	5.37 ± 1.29	0.47	P>0.05**
After program	10.4 ± 2.38	5.37± 0.97	10.38	P<0.05*
t-value	-22.08	0.00		
% of changes	%87.05	%0.00		
P-value	P<0.05 *	P>0.05**		

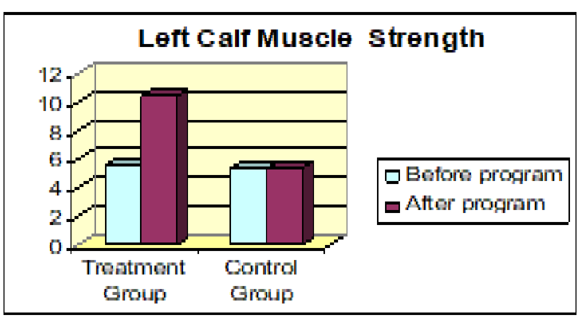
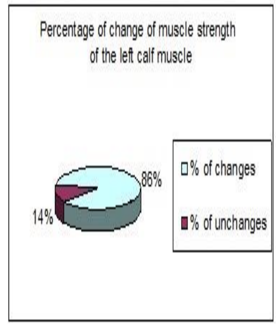


Fig (16): Statistical analysis for muscle strength of the Left Calf muscle before and after the treatment program



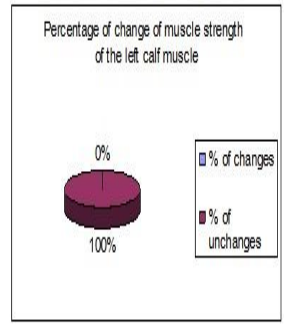


Fig (17): Percentage of change of muscle strength of the left calf muscle before and after treatment for study and control group

Discussion:-

Our present investigation was designed to investigate whether low frequency electrical stimulation of quadriceps and calf muscles has a beneficial effect on muscles strength in patients with chronic heart failure (CHF) or not, with the hypothesis that there may be no effect of low frequency electrical stimulation on muscle strength in patient with chronic heart failure (CHF) classes III-IV.

Fifty patients diagnosed with CHF, classified as New York Heart Association (NYHA) classes lll to lV, on optimal medical treatment (angiotensin converting enzyme inhibitor(ACEI,) betablockers , diuretics) were randomly selected from Cairo university hospitals (cardiology department) randomly assigned into two groups, study group thirty patients and, control group twenty patients, Each subject of the study group received electrical stimulation for one hour/day, five days a week, for three consecutive weeks in addition to medical treatment, on the other hand each subject of the control group received medical treatment only , Pre and post program muscles strength assessment was done for each subject of both groups.

These results are very similar to those observed in another study; thirty patients with CHF and NYHA class II-III were randomly assigned to a rehabilitation program using either electrical stimulation of skeletal muscles or bicycle training; five weeks of (LFES) applied simultaneously to the quadriceps and calf muscles of both legs (thirty minute/day for five days/week); and bicycle training((thirty minute /day for five days/week) aerobic exercise led to significant (increase functional capacity, distance walked in 6 minutes, and of HRmax) in both groups., the improvement in functional capacity seems to be mediated through the improvement in transport mechanisms, which itself appears to be the result of improved maximal workload and exercise duration [11]**.**

Nuhr, [20], .Published the results of another study population comprised twenty-four patients with stable, chronic congestive heart failure. (NYHA Functional classes II, III). The patients were randomized to enter either a classical bicycle training program, or an electrical stimulation program. Symptom limited spiroergometry was examined before and after training. The patients in the bicycle group (group 1) underwent (five daily sessions of twenty minute bicycle exercise), at 60–80% of their maximal heart rate. For five weeks, in the electrical stimulation group (group 2), low-frequency (10 Hz) LFES was applied to both quadriceps and calf muscles. (Five daily LFES sessions of one hour were achieved) for five weeks. The following parameters were collected before and at the end of the rehabilitation program: This study showed that: Improvement of exercise capacities in patients with chronic heart failure can be achieved either by classical bicycle training or by electrical stimulation

Similarly, Eicher, [8], Published another two randomized trials showed that both home-based electrical stimulation of the legs and classical exercise training can significantly increase muscle strength and quality of life and improve oxygen uptake after several weeks of stimulation in patients with CHF. These results were confirmed also in the present study. The increases in functional capacity and distance walked in 6 minutes, and also the exercise duration after eight weeks of LFES were very similar to the increases in these parameters in the bicycle group**.**

In agreement, Delay, 2005, [5] compared LFES and conventional exercise training in a group of stable CHF patients. Bilateral quadriceps and calf muscles,: NMES, 10 Hz, biphasic On/off time: 12/8 s Pulse duration: 200 μs Amplitude set to highest tolerable for the patient 60 min/d, 5 d/wk., 5 wk. Conventional exercise: Aerobic exercise (treadmill, bicycle and arm cycling) at 60–70% peak HR; target exertion by Borg scale 13–15, 60 min/d, 5 d/wk., 5 wk. Significant increase in the NMES group: Peak VO2 (8.2%), 6MWTD (11.9%), Maximal knee extensor isometric contraction at 90º (9.7%) Significant increase in the bicycle group: Peak VO2 (21.8%), 6MWTD (15.3%), Maximal knee extensor isometric contraction at 90º (11.3%) Aforementioned improvements were not statistically significant between groups.

Petr Dobsak, [23][24], compared the home-based (LFES) training and bicycle training; the results demonstrated that both methods could significantly influence the muscle strength, improve functional parameters and improve also the quality of life in patients with (CHF) (NYHA class II-III) Patients in the first group (n = 15) had eight weeks of home-based low-frequency electrical stimulation (LFES) applied simultaneously to the quadriceps and calf muscles of both legs (1 h/day for seven days/week); patients in the second group (n = 15) underwent eight weeks of (forty minute aerobic exercise) (three times a week).after the eight weeks. Period significant increases in several functional parameters were observed in both groups:

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maximal VO2 uptake, maximal workload, distance walked in 6 minutes, and exercise duration. These results demonstrate that an improvement of exercise capacities can be achieved either by classical exercise training or by home-based electrical stimulation. LFES should be considered as a valuable alternative to classical exercise training in patients with CHF.

Similar experiences have already been reported in the studies by Karavidas, 2008, [16], Deley, 2008, [6] and Deftereos, [4] and De Araujo, [3] and also Karavidas, 2013, [15], compared LFES and conventional exercise training in a group of stable CHF patients. Bilateral quadriceps and calf muscles,: NMES, 25 Hz, biphasic On/off time: 5/5 s Amplitude set to elicit a muscle contraction without discomfort or significant movement at knee or ankle joints 30 min/d, 5 d/wk., 6 wk. Control: Same NMES protocol but amplitude set to a level that did not elicit a muscle contraction No adverse events reported. Significant increase in the NMES group: 6MWTD (9.3%), Quality-of-life score (37.2%).

Banerjee, [2], compared LFES and conventional exercise training in a group of stable CHF patients: Bilateral quadriceps, hamstrings, calf muscles, and gluteal muscles 4 Hz, rhythmic contraction Maximum current: 300 mA Intensity: 90% of heart rate reserve, determined individually 60 min/d, 5 d/wk., 8 wk. Washout phase: Return to habitual physical activity level No adverse events reported but inability to tolerate NMES was the drop out cause for 2 patients Significant increase in the NMES group: Peak VO2 (10%), 6MWTD (9.6%), maximal knee extensor isometric contraction at 90º (7.1%) No significant difference in the aforementioned variables between baseline and washout. The greatest improvements were achieved by those with the lowest baseline exercise capacity and strength. No changes in LVEF and diastolic function.

Similarly, Dobsak, [7], reported in the study that NMES: bilateral quadriceps and calf muscles, 10 Hz, biphasic On/off time:20/20 s Intensity: 60 mA 60 min x 2/d, 7d/wk., 12 wk. ET: 12 wk. total with bicycle: 40 min 2 wk., 20 min in the last 10 wk. and resistance training 20 min last 10 wk. No adverse events reported Significant beneficial effects in the NMES group: Peak VO2 (9.8%), Big-endothelin pmol/L (-25%), CRP mg/L (-65.3%) Significant beneficial effects in the aerobic ET group: Peak VO2 (11.2%), Big-endothelin pmol/L (-8.2%), CRP mg/L (-60%) Aforementioned improvements were not statistically significant between groups No changes in LDL, HDL and glucose level Positive effect after 12 weeks of ET or NMES on arterial stiffness and autonomic balance in patients with moderate CHF

In agreement**,** Labrunee, [17], reported that: NMES, left leg quadriceps and triceps surae muscle, 25 Hz Duration: 5 min On/off time: 3/3 s TENS: left leg quadriceps and triceps surae muscle Current non polarized, 80 Hz, Duration: 5 min On/off time: 3/3 s cross over, randomized and sham controlled No adverse events reported Significant beneficial effects in the NMES group: reduce MSNA Significant beneficial effects in the NMES group: reduce MSNA No variation of blood pressure, heart rate or respiratory parameters was observed after stimulation

In agreement, Parissis, [22], reported that bilateral quadriceps and calf muscles,: NMES: 25 Hz On/off time: 5/5 s Intensity: visible muscular contraction to pain threshold 30 min/ d, 5 d/ wk., 6 wk. Placebo: Bilateral quadriceps and calf muscles, 5 Hz (did not lead to palpable contractions 30 min/ d, 5 d/ wk., 6 wk. No adverse events reported significant beneficial effects in the NMES group: FMD (120%), KCCQ, MLHFQ scores, BDI questionnaires and Zung self-rated depression scores. Significant difference between groups: FMD, quality of life and depression

On the other hand**,** Soska, [28], reported that bilateral extensors muscle,: NMES, 10 Hz, On/off time: 20/20 s 60 min x 2/ d, 7 d/wk., 12 wk. AT: Bicycle, 10 min+40 min +10 min, 3x/wk., to individual anaerobic threshold, first 2 wk. AT 20 min and resistance training 20 min for the following 10 wk. AT + NMES: identical AT + identical NMES, 12wk No adverse events reported Significant beneficial effects in the NMES group: Peak VO2 8.3%), Duration of exercise min (9.4%), quality of life MLHF score (-16.6%) Significant beneficial effects in the AT group: Peak VO2 (15.2%), Duration of exercise min (19.8%), quality of life MLHF score (-27.9%) Significant beneficial effects in the AT+NMES group: Peak VO2 (15.3%), Duration of exercise (min) (10.7%), quality of life MLHF score (-29.1%) The results of the three studied rehabilitation training protocols did not significantly differ statistically. It can be stated that aerobic ET combined with EMS adds no statistically significant benefit

Palau, [21], concluded that NMES: bilateral quadriceps and gastrocnemius muscles, 10-50 Hz On/off time: 5/5 s Intensity: pain threshold 45 min/d, 2 d/wk., 12 wk. IMT: 20 min x 2/d, 7 d/ wk., 12 wk. IMT + NMES: identical IMT + Identical NMES Standard treatment: no IMT, NMES Ongoing

Similarly, Kadoglou, [14], concluded that bilateral quadriceps and gastrocnemius muscles,: NMES 25 Hz On/off: 5/5 s Intensity: visible muscular contraction 30 min/d, 5 d/ wk., 6 wk. Placebo: 5 Hz, not leading to a visible or palpable contraction No adverse events reported Significant beneficial effects in the NMES group: 6MWT, hospitalization rate. Patients after NMES had no difference compared to non-NMES patients in terms of survival the hospitalization rate was significantly lower in the NMES group before and after adjustment for major prognostic factors

Conclusion

Functional low frequency electrical stimulation of quadriceps and calf muscles improved muscles strength in patients with chronic heart failure, and offered an alternative training mode. Thus we recommended using functional low frequency electrical stimulation of quadriceps and calf muscles in order to improve muscles strength, reduce pain and swelling in patients with chronic heart failure.

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